

APPENDIX C

B. Kitterman

CANADIAN ELECTRICAL ASSOCIATION

Metering Section

Engineering and Operating Division

May 1991
Toronto

**ELECTRONIC METERING AND
APPLICATIONS INTO THE 90's**

I. Steklac, P.Eng.
Schlumberger Industries
Electricity Division
215 Laird Drive
Toronto, Ontario, Canada M4G 3X1

SUMMARY

The beginning of a new decade has seen the metering industry embarking into a new domain in metering technology: solid-state electronics. The accuracy, versatility, and flexibility of these devices ensures their rapid acceptance and strong foothold in the metering market place. A thorough understanding of the underlying technologies, their features, benefits, and short comings is absolutely necessary in order to chose the appropriate meter for a given application. This paper first presents the most common electronic metering technologies, along with their significant merits and pitfalls, then goes on to discuss various applications of these technologies in modern metering practice.

Keywords: Mark Space Amplitude (MSA), Hall Effect, Transconductance, Digital Sampling

1. INTRODUCTION

In about 1884, Dr. Galileo Ferraris of Turin, Italy demonstrated that torque could be produced electromechanically on a metallic object by the interaction of two alternating current fluxes, with a time and space displacement, impressed upon the object. Thus was born the induction meter principle which, realized in product form, has provided faithful service to the metering industry for close to a hundred years.

Originally, the induction principle was not the only technology to be employed. Early metering developments brought about several innovative products — meters utilizing electrolytic deposition, balance beam devices driven by differential heating of gas filled canisters, fan type assemblies driven convection currents from electrically heated elements (see Figure #1). Eventually the industry standardized on the induction principle for its combined virtues of simplicity, accuracy, and longevity.

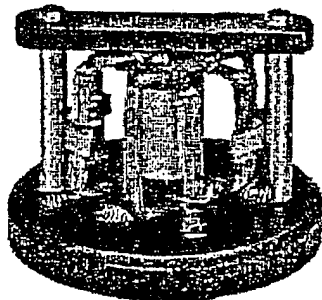
Electronics entered onto the metering scene in the mid 1970's with the introduction of solid-state recorders and metering attachments. Fully solid-state meters have only recently become accepted, and as with the early metering devices, several incarnations of the basic principle exist. This paper reviews

four basic forms of electronic metering, as well as some of applications and major features that this new technology has to offer the metering industry today, and for the decade to come.

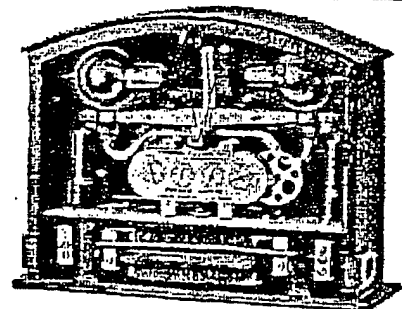
2. REVIEW OF ELECTRONIC METERING TECHNOLOGIES

In attempting to both replicate and improve on the principle of induction metering, several electronic technologies have been developed. For the most part an electricity meter, be it electromechanical or electronic, can be divided into four types of elemental components: sensors, multipliers, numerical conversion, and registers. Sensors provide the interface between the incoming voltage and current and the metering circuit. Multipliers perform the heart of the metering function by providing the product of voltage and current. Numerical conversion is the process of transforming the output of the multiplier stage, or product term, into a form that can be processed by a register. Registers are devices that store and display the metered quantities.

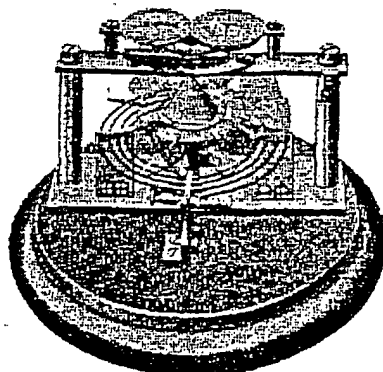
The transition from electromechanical to solid-state metering was initiated through the use of hybrid meters. These devices employed an induction meter



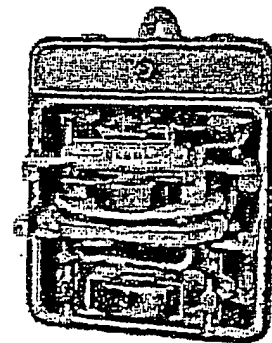
Ferraris Meter (1888)



Thomson Beam Meter (1904)



Forbes' Windmill Meter (1888)



Shallenberger Induction Watthour Meter (1896)

Taken from *Electricity Meter History and Progress*,
R.C. Lanphier, Sangamo Electric Company, 1925

Figure 1 Electromechanical Meter History

to measure power, and an electronic register. The register encoded and stored the measured quantity, displayed it, and manipulated it to derive further quantities of interest. Although a hybrid meter is more expensive than the electromechanical meter alone, the increased flexibility and versatility of the electronic register has added value to the overall product. The success of hybrid technologies prompted the industry to extend this trend to fully solid-state metering.

To date, four basic forms of electronic metering have been successfully introduced to the industry: Mark-Space Amplitude, Hall Effect, Transconductance, and Digital Sampling. With the exception of digital sampling, each form uses equivalent sensor, numerical conversion, and register components, for the most part. The only major difference and innovation between these forms of solid-state metering is the multiplier component (see Figure #2). Digital sampling slightly confuses the issue by swapping the order in which the numerical conversion and multiplication components operate.

Each electronic metering technology, along with its benefits and shortcomings, is described in detail in the following sections.

2.1 MARK-SPACE AMPLITUDE

Mark Space Amplitude (MSA), or Time Division Multiplexing as it is also known, is a well established form of electronic metering. The technique is based on analogue multiplication of instantaneous voltage and current waveforms to derive power, which is output as a series of pulses (see Figure #3). In its simplest form, an MSA meter is comprised of a waveform generator, a comparator, a set of electronic switches, a low pass filter, and a voltage controlled oscillator.

One source signal, usually voltage, is applied to one input of the comparator. The other input is tied to the waveform generator, which produces a precision triangular waveform of fixed amplitude and high frequency. The comparator is configured such that the output is high whenever the amplitude of the voltage exceeds that of the triangular waveform. Thus, for an alternating voltage signal, a series of pulses is generated, the duration of which are proportional to the instantaneous amplitude of the voltage. This pulse stream, along with its inverse, controls the duty cycle of a set of electronic switches.

The other source signal, current, is converted to a voltage via a burden resistance and fed into one of

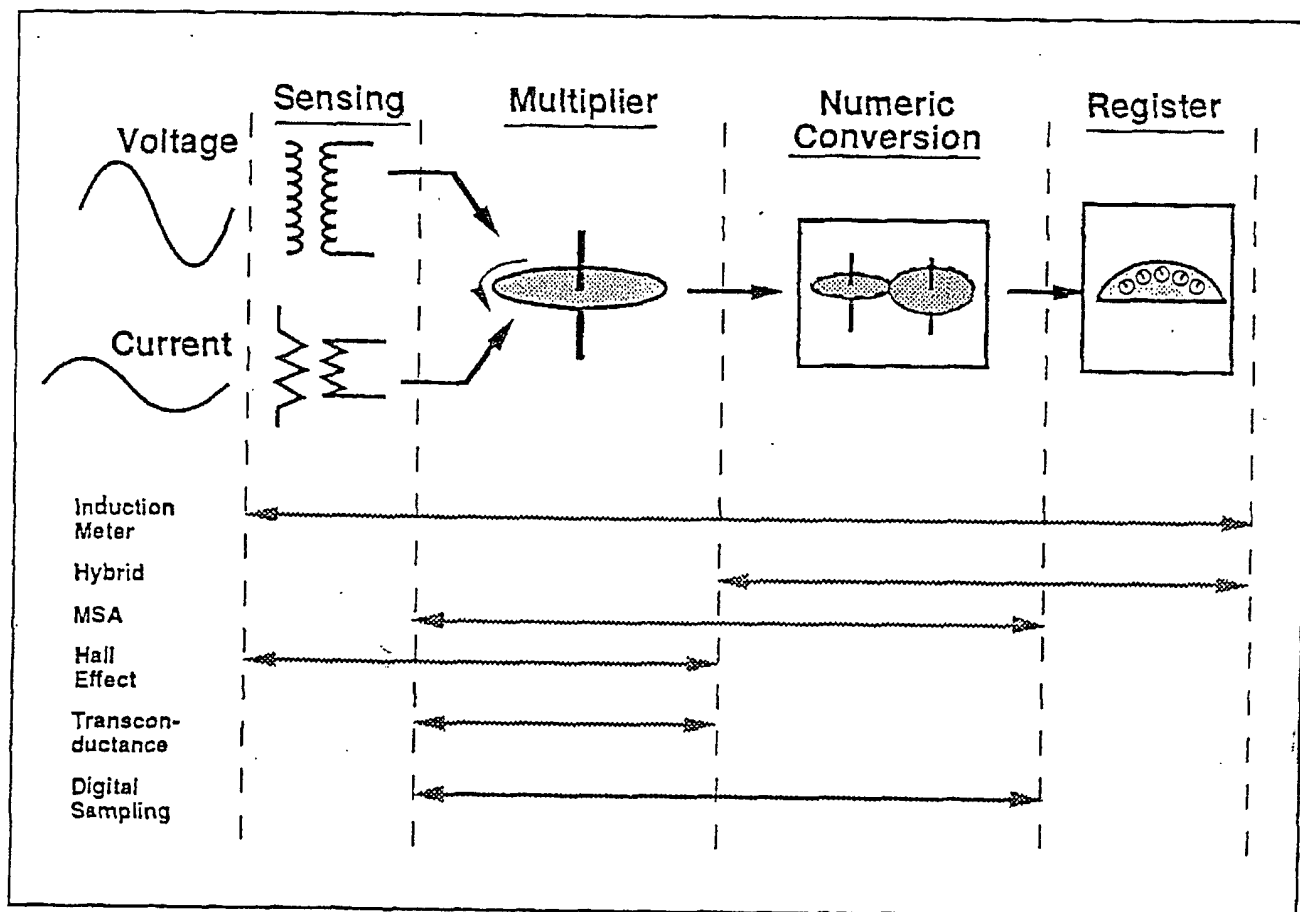


Figure 2 Electricity Meter Components

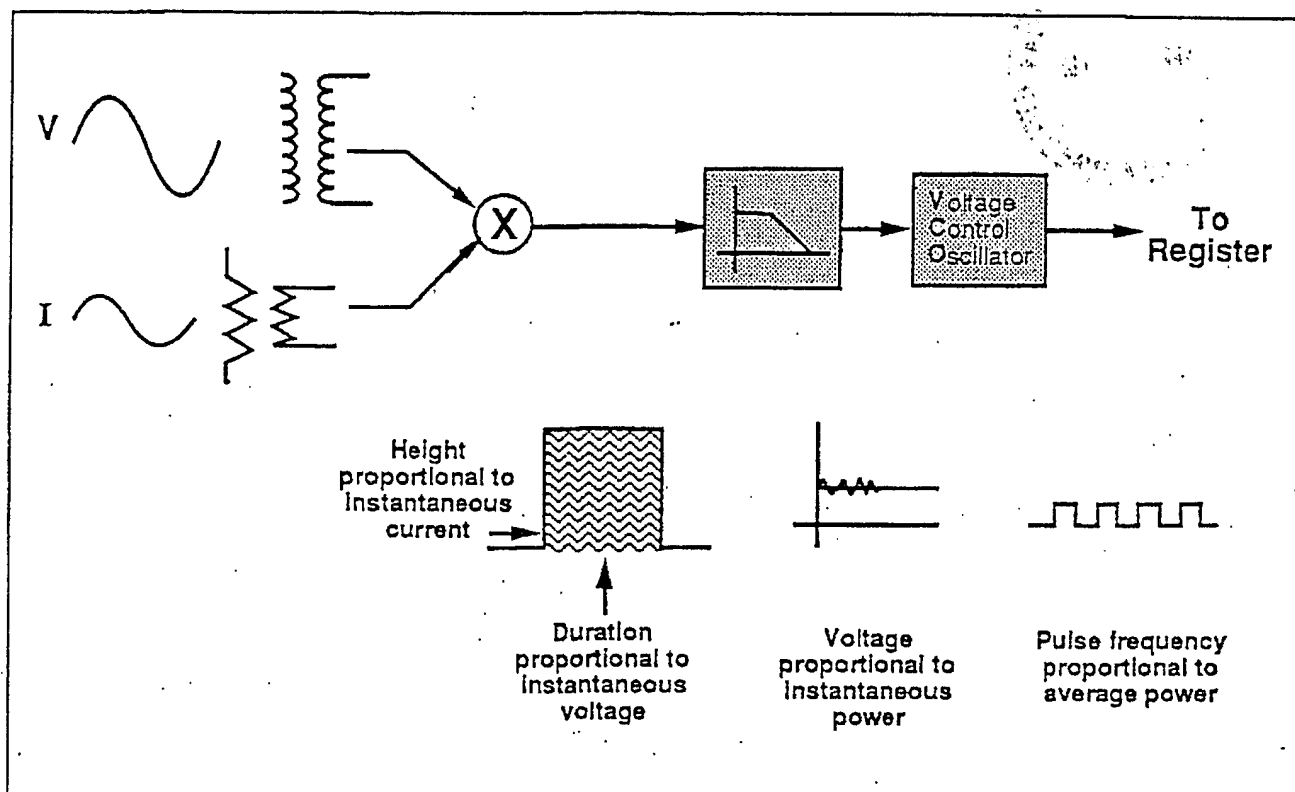


Figure 3 MSA Block Diagram

the electronic switches. The other switch is fed the inverse of the first. The output of these switches is combined to form a signal with amplitude proportional to instantaneous current, and a duration proportional to instantaneous voltage. Thus, the average value of this waveform is equal to instantaneous power (see Figure #4).

Averaging is accomplished by means of a low pass filter which converts the waveform into a voltage proportional to instantaneous power. This voltage is converted to a series of pulses by means of a voltage controlled oscillator (VCO), or voltage to frequency converter, which can then be accumulated by a register as energy values.

Performance achieved by a good MSA design usually exceeds traditional 0.5% accuracy classifications at unity and power factor, for a dynamic range in excess of a 100:1. Classically the multiplier and converter circuitry are combined onto a single monolithic integrated circuit. This results in a metering technology with a very good cost-to-accuracy ratio. Given a stable waveform generator and VCO, MSA meters exhibit excellent linearity and reliability. Performance under conditions of distortion is limited by the frequency of the triangular waveform and the cut off frequency of the low pass filter. Isolation is as good as the transformers providing the voltage and current signals.

Direct measurement using this technique is limited to Watts and VARs (obtained by phase shifting voltage 90 degrees lag with respect to current). Volt-amperes must be derived vectorially (the square root of the sum of the squares of Watts and VARs). Costs also increase dramatically for polyphase metering if per phase information is required. Calibration is necessary in hardware, and with the advent of EEPROM potentiometers can be automated under software control.

Principally, MSA technology is best utilized in residential single phase watt-hour metering.

2.2 HALL EFFECT

The Hall effect is a well-known physical phenomenon, predating even Ferraris' discovery, which can be harnessed as a solid-state multiplier for metering. Basically, if certain types of current conducting materials are subjected to a perpendicular magnetic field, a voltage proportional to the product of the current and the magnetic field strength will develop across ends of the material (see Figure #5).

A simple single phase 3-wire meter can be easily built from a Hall multiplier as shown in Figure #6. A Hall material is placed within the air gap of a current core, through which power lines are run in additive

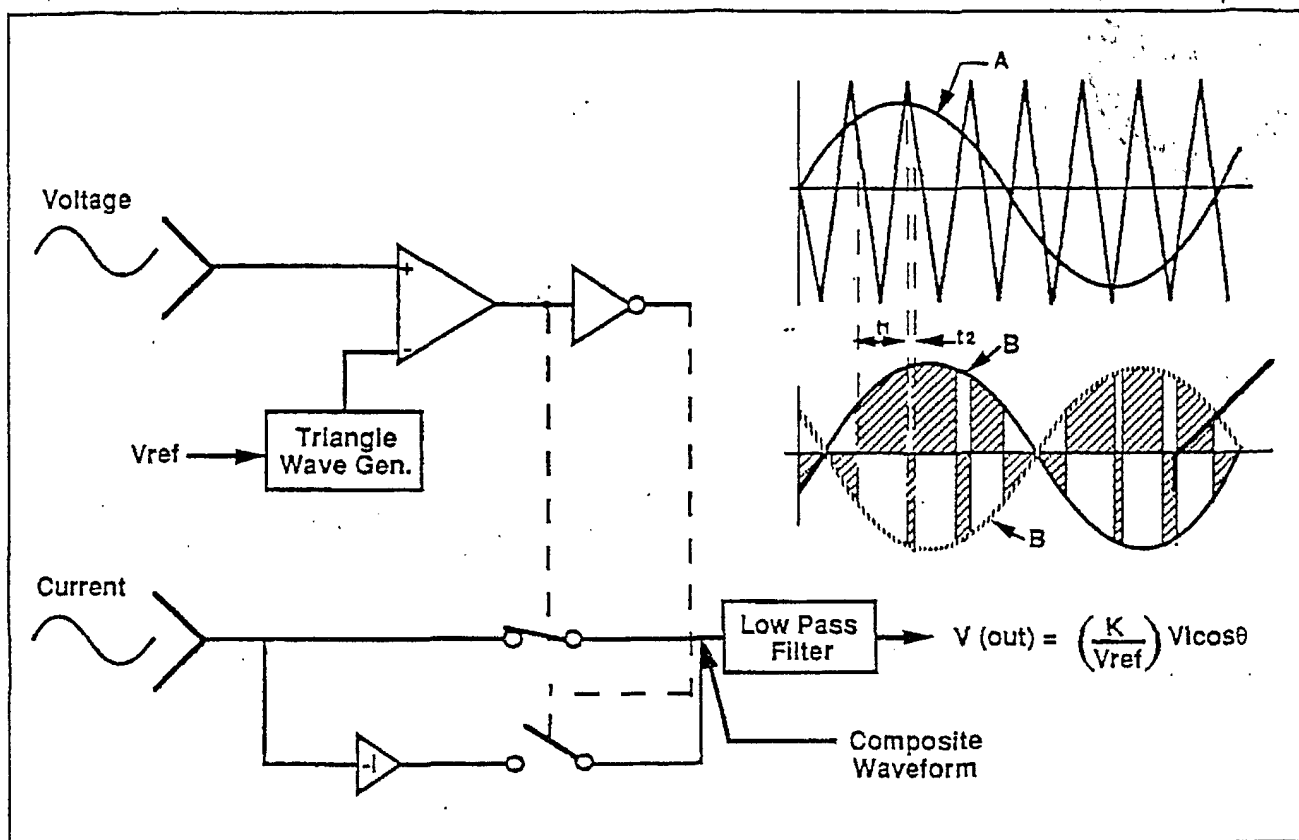


Figure 4 MSA Multiplier Block Diagram

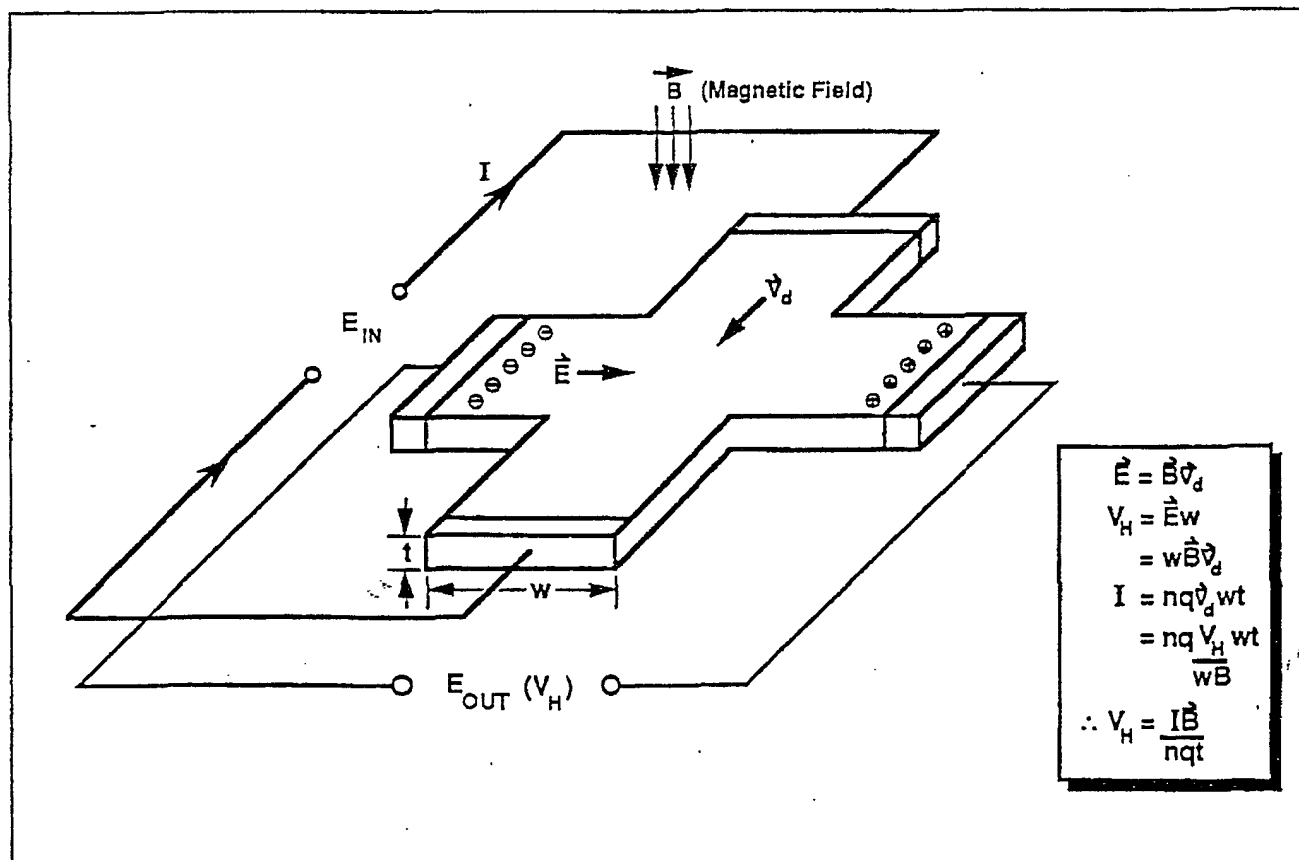


Figure 5 Hall Effect Principle

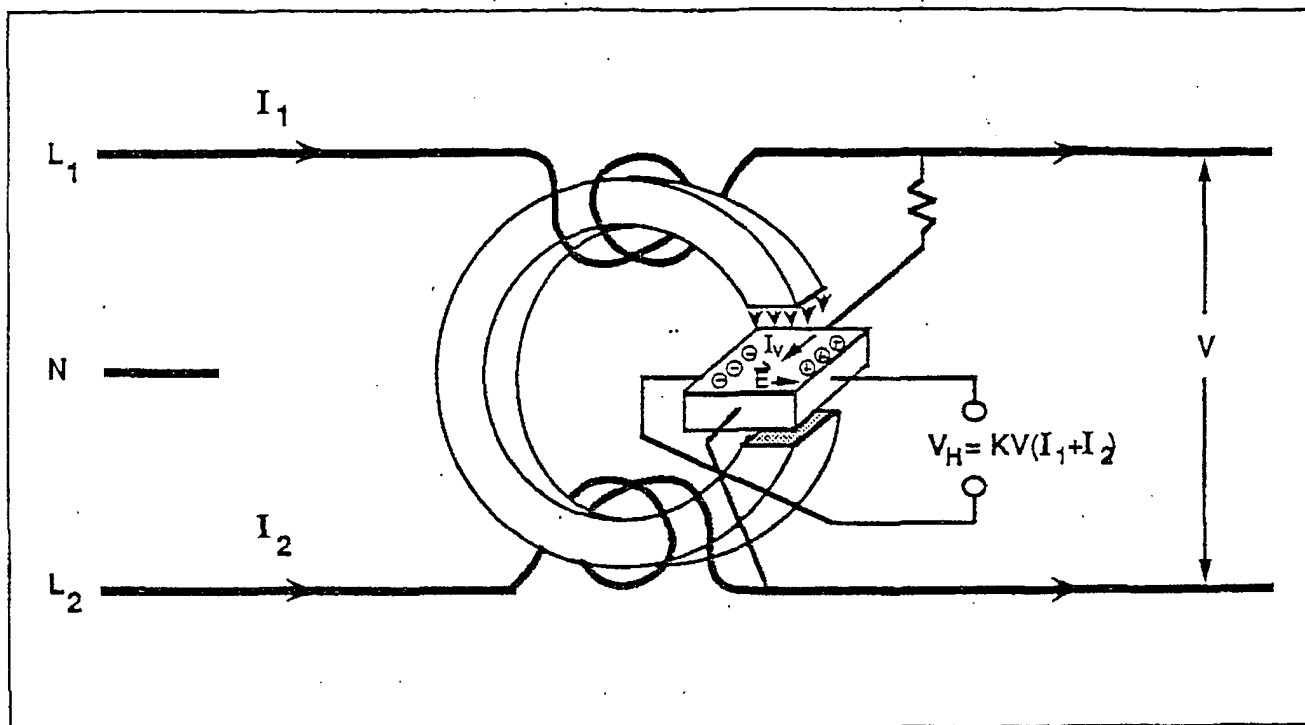


Figure 6 Hall Effect Multiplier

manner, thus, it sees a strong magnetic field proportional to the sum of the line currents. By connecting the device to the power line voltage by means of a series resistor, a current proportional to the line voltage will be conducted through the Hall material. The developed Hall voltage will then be a product of the line voltage and sum of the line currents, therefore, proportional to instantaneous line power. To be useful, this voltage is averaged by a low pass filter and converted to a pulse stream by means of a VCO. This pulse stream is then fed to a register (see Figure #7).

As with MSA multipliers, Hall effect transducers are very cost effective and can be made to measure Watts and VARs, but not volt-amperes. The linearity of a Hall effect transducer is somewhat less than that of MSA, which limits its accuracy to the more traditional 1% and 2% classifications. However, Hall effect transducers are able to respond accurately to significant harmonic content, as well as any d.c. components, because neither the voltage nor current waveforms feeding the Hall material need to be sinusoidal. Isolation is also very good because the load current does not flow within the Hall material, and any transients on the line voltage can be effectively eliminated by making the series resistance between the line and the Hall material fairly large.

Difficulties arise with Hall effect metering when the current core is subjected to large temperature variations. Exposed to varying temperatures, the open core will have difficulty maintaining its shape, and in particular the size of the air gap into which the

Hall transducer is positioned. The strength of the magnetic field through this air gap is directly proportional to the size of the gap. Thus, if the magnetic field strength varies with temperature, so will the power output of the Hall transducer.

As with MSA, Hall effect technology lends itself best to residential, single phase watt-hour metering.

2.3 TRANSCONDUCTANCE

Transconductance is another form of metering that incorporates analogue multiplication of voltage and current (see Figure #8). In its simplest form this technology uses a differential transistor pair to amplify a current by a variable gain proportional to a voltage.

A fairly simple single phase, 3-wire meter consists of a toroidal current transformer through which both line currents are passed in an additive manner (see Figure #9). Using a burden resistance, the secondary current of the transformer is converted to a voltage and applied across the bases of the two transistors, acting in a manner that controls the current through their emitter-collector junctions. The line voltage is applied between the collectors (through current limiting resistors) and the emitters of the transistors (by means of a series resistance). Thus, a current proportional to the line voltage is developed between the emitter-collector junctions of the transistors when conducting.

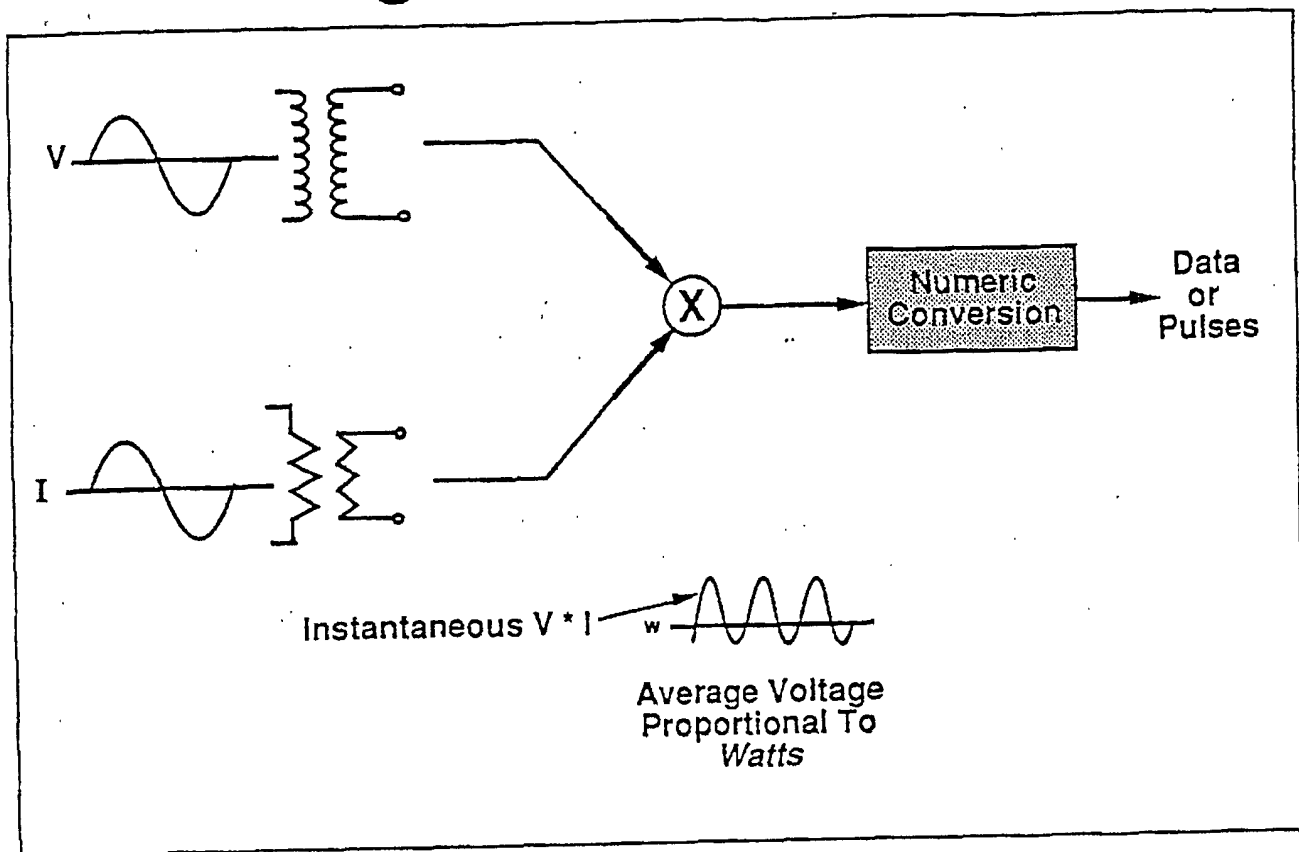


Figure 7 Hall Effect Block Diagram

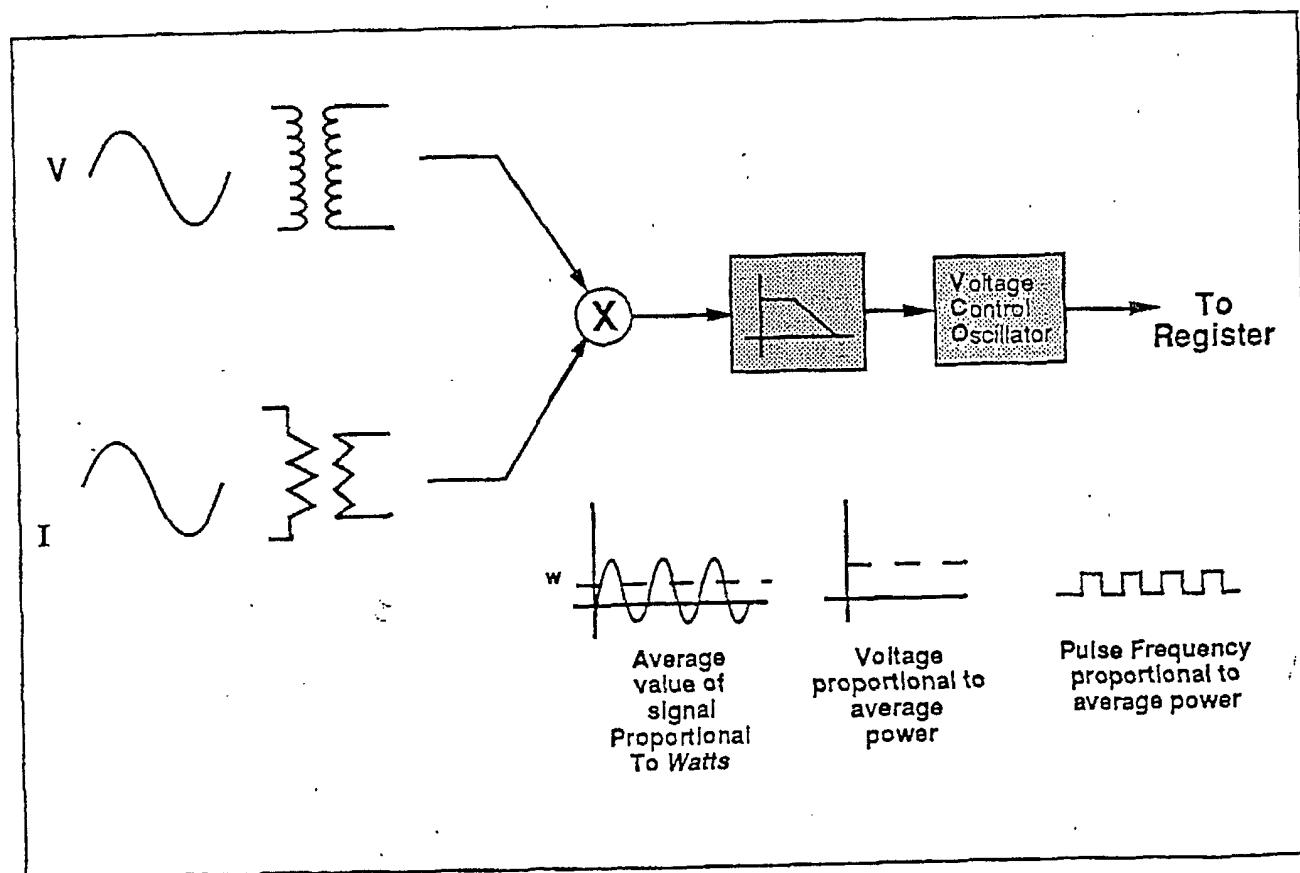


Figure 8 Transconductance Block Diagram

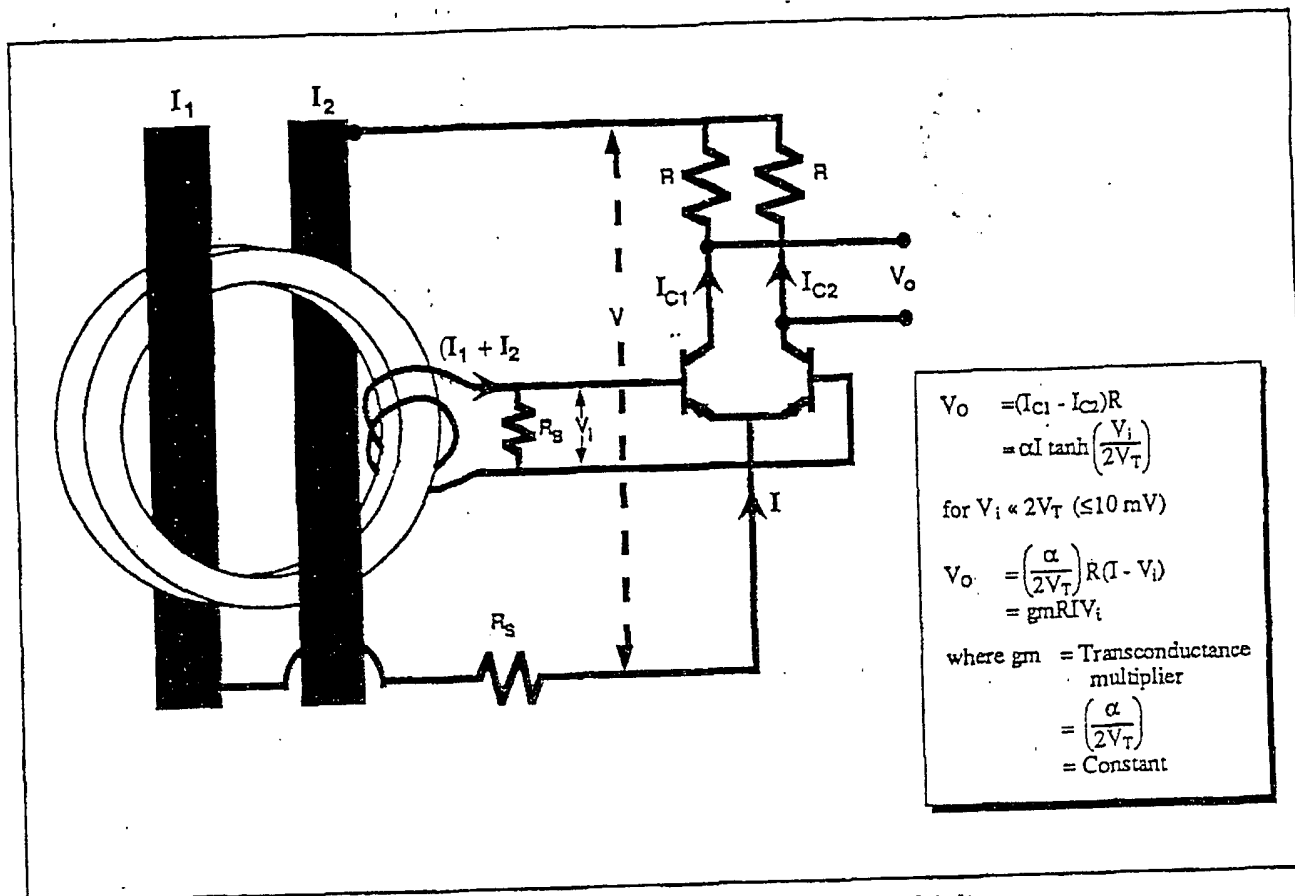


Figure 9 Two Quadrant Transconductance Multiplier

When correctly biased by the base-emitter voltage, the currents that flow in the emitter-collector legs of each transistor are not equal. This creates a potential difference between the two collector legs. This voltage is the product of the line voltage and line currents and is therefore proportional to the line power. It can be shown mathematically that this voltage is a product of the resistance of the collector legs and the difference in the collector currents. Furthermore, this difference in currents is equal to the hyperbolic tangent of the base-emitter voltage divided by the transistor's thermal voltage (V_T). If the base-emitter voltage is kept very small (much less than $2 \times V_T$), this relationship may be simplified to the product of the base-emitter voltage and the current.

The final two stages of a complete transconductance meter are identical to those found in both the MSA and Hall effect type devices. A low pass filter is used to average the output voltage, such that it is proportional to instantaneous power, and a VCO is used to convert this voltage to a series of pulses. This resultant pulse stream can be fed to a simple counting register.

As with the Hall effect transducer, a transconductance multiplier provides an excellent cost to accuracy ratio. The differential pair can be easily combined onto a single integrated circuit. As a matter of fact, most operational amplifiers have a differential pair in their

input stages. Difficulties with this technology arise in providing the relatively small base-emitter voltage (derived from the transformed line current) which must be on the order of ten millivolts or less. Current transformers that exhibit linearity at such low output levels are quite expensive, leaving shunt metering much more viable. Shunts however are not appropriate for North American 3-wire installations due to their inherent isolation problems.

An additional complication arises when a detailed examination of the multiplier is made. A single differential pair provides only a two quadrant multiplier, which will have large errors at certain phase angles. Expanding on the principle, a four quadrant amplifier can be designed using two differential pairs and a constant current source. This design exhibits superior performance under varying power factors and harmonic distortion than the two quadrant multiplier.

2.3 DIGITAL SAMPLING

Digital sampling is the only electronic metering technology that does not use an analogue multiplier. In this process, the analogue values of voltage and current are converted to digital data prior to any multiplication taking place (see Figure #10).

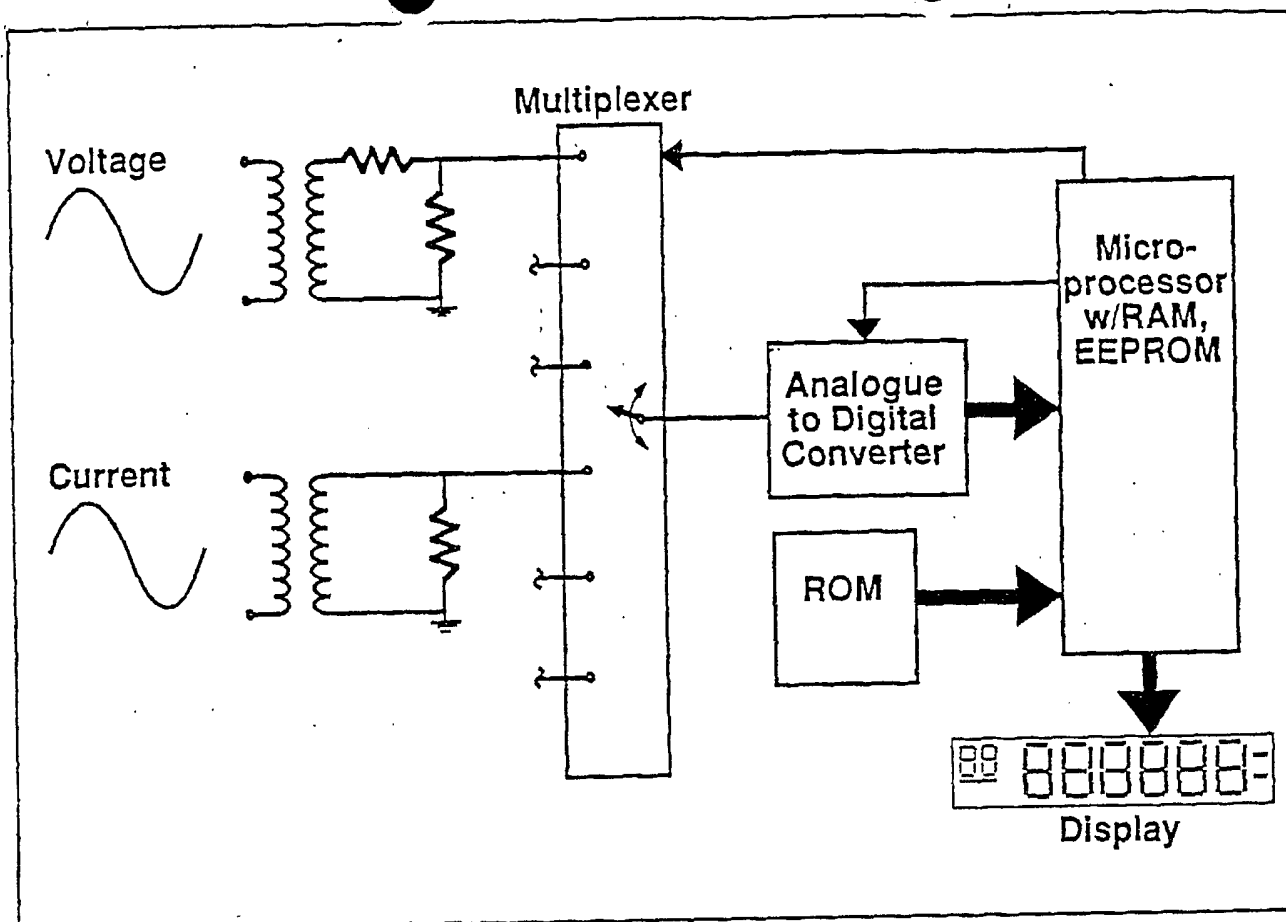


Figure 10 Digital Sampling Block Diagram

A meter employing digital sampling must also transform the line quantities of voltage and current to levels more appropriate to digital circuitry. Line voltages are passed through potential transformers and then through a resistive divider to obtain an appropriate signal. Line currents are passed through current transformers and then converted to an appropriate voltage signal by means of a burden resistance. These voltages are then passed to an analogue switch, or multiplexer, which determines which signal gets input into the analogue to digital converter (ADC). This switch and the ADC are controlled by a microprocessor or microcontroller.

The addition of a microprocessor facilitates the derivation of numerous metering quantities. For instance: real power can be derived from the product of in phase voltage and current samples; reactive power can be derived from the product of current and ninety degree lagging voltage samples; and apparent power can be derived either vectorially, as the square root of the sum of the squares of real and reactive powers, or arithmetically, as the product of RMS voltage and current samples. Most inaccuracies can also be fully compensated algorithmically, eliminating the need for any physical calibration of the meter (see Figure #11).

For residential (single-phase) applications, digital sampling does not represent the most cost effective solution compared to MSA, Hall effect, or transconductance. However, for industrial or polyphase applications, the technology comes into its own. By increasing the number of inputs to the multiplexer, a single phase meter can be scaled up to a polyphase by simply adding potential and current transformers for each additional phase. Of course the microprocessor must be capable of supporting the additional computational burden, and the ADC must be capable of more rapid sampling.

The accuracy and dynamic range obtainable with digital sampling is comparable to that of MSA, and determined by the size and linearity of the ADC. The larger the ADC conversion size, the better the accuracy and dynamic range, however, the greater the cost of the device. Unfortunately, this cost to performance ratio of ADC technology is exponential, thus most meters employing digital sampling utilize methods such as gain staging, or dither-noise techniques to improve their performance. Since both voltage and current inputs are passed through transformers, there are no inherent isolation problems to speak of.

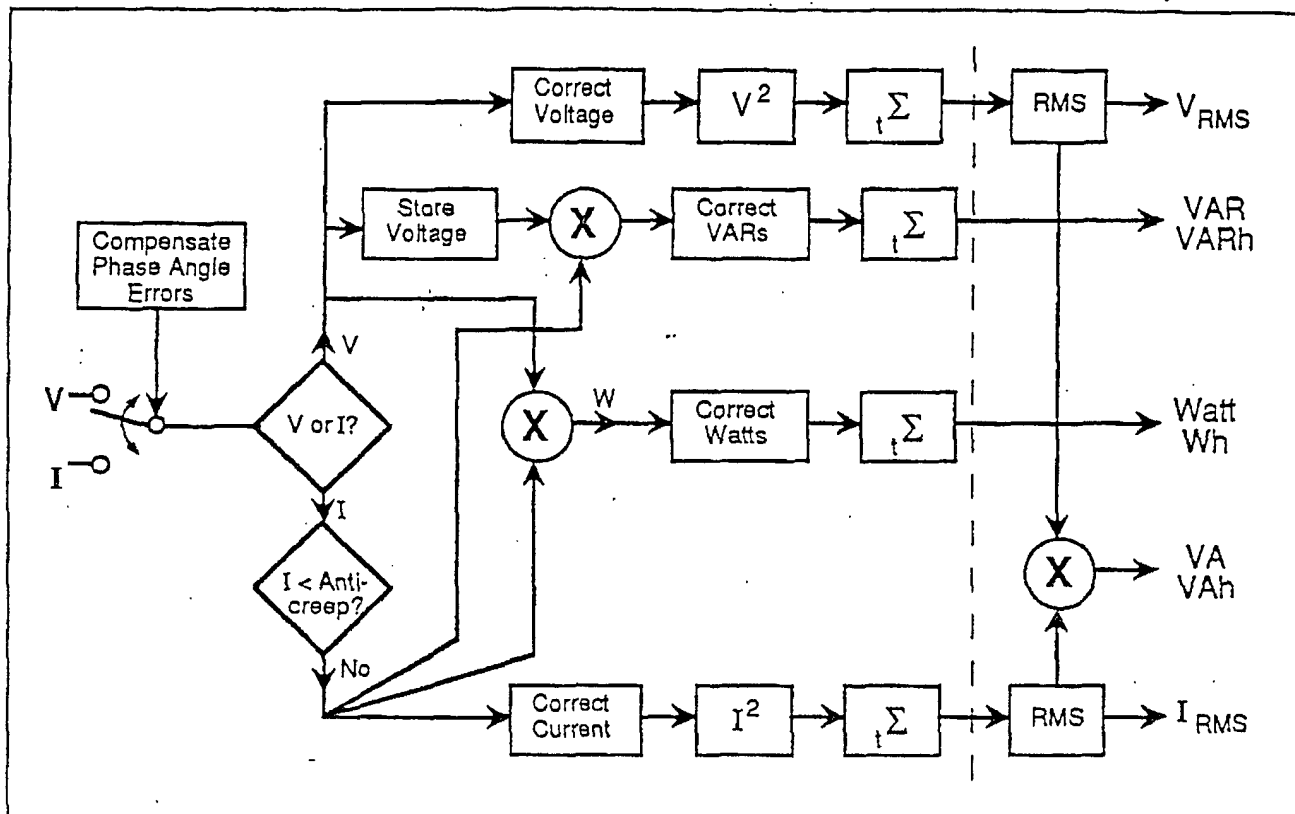


Figure 11 Digital Sampling Multiplier

2.4 OPTICAL SENSORS

Optical sensor technology does not represent a solid-state metering technique on its own. It does however offer a glimpse of possible future directions in the metering industry.

Optical measurement of current is possible using a derivative of Faraday's effect. If an optical fiber carrying polarized light is placed perpendicular to a current carrying conductor, a change in the polarization of the light will occur that is proportional to the magnetic field strength generated by the conductor (see Figure #12). By measuring this change in polarization, a value proportional to current can be derived. Optical measurement of voltage is similarly possible using Pockel's effect. If an optical fiber carrying polarized light is placed in an electric field, a change in the polarization of the light will occur that is proportional to the electric field strength produced by a potential difference (see Figure #13). By measuring this change in polarization, a value proportional to voltage can be derived. Optical measurement of voltage can also be extended to the measurement of d.c. quantities utilizing the optical equivalent of a Wheatstone bridge architecture. This theory is beyond the scope of this paper.

The benefits of optical measurement include total isolation, complete electromagnetic interference

(EMI) immunity, no hysteresis or losses due to ferromagnetic materials, and very high bandwidth. Although extremely expensive for end-user metering, optical measurement techniques may one day find their way into the measurement of transmission line environments, or very large loads where safety and immunity are paramount.

2.5 TECHNOLOGY OF CHOICE

Which is the electronic metering technology of choice? It clearly depends on the application. Each technology provides benefits and pitfalls, and each is ideally suited to a specific utilization. Figure #14 presents a tabular summary of the four technologies compared to one another.

The phenomenal success and longevity of the electromagnetic induction meter has fostered very specific market conditions, and requirements. Price to performance and functionality ratios are clearly established, which can create barriers to the introduction of new technology. Currently in North America, fully solid state metering is reserved to polyphase industrial installations only. The technology as yet cannot overcome the cost impediments currently in place in the single phase, residential marketplace.

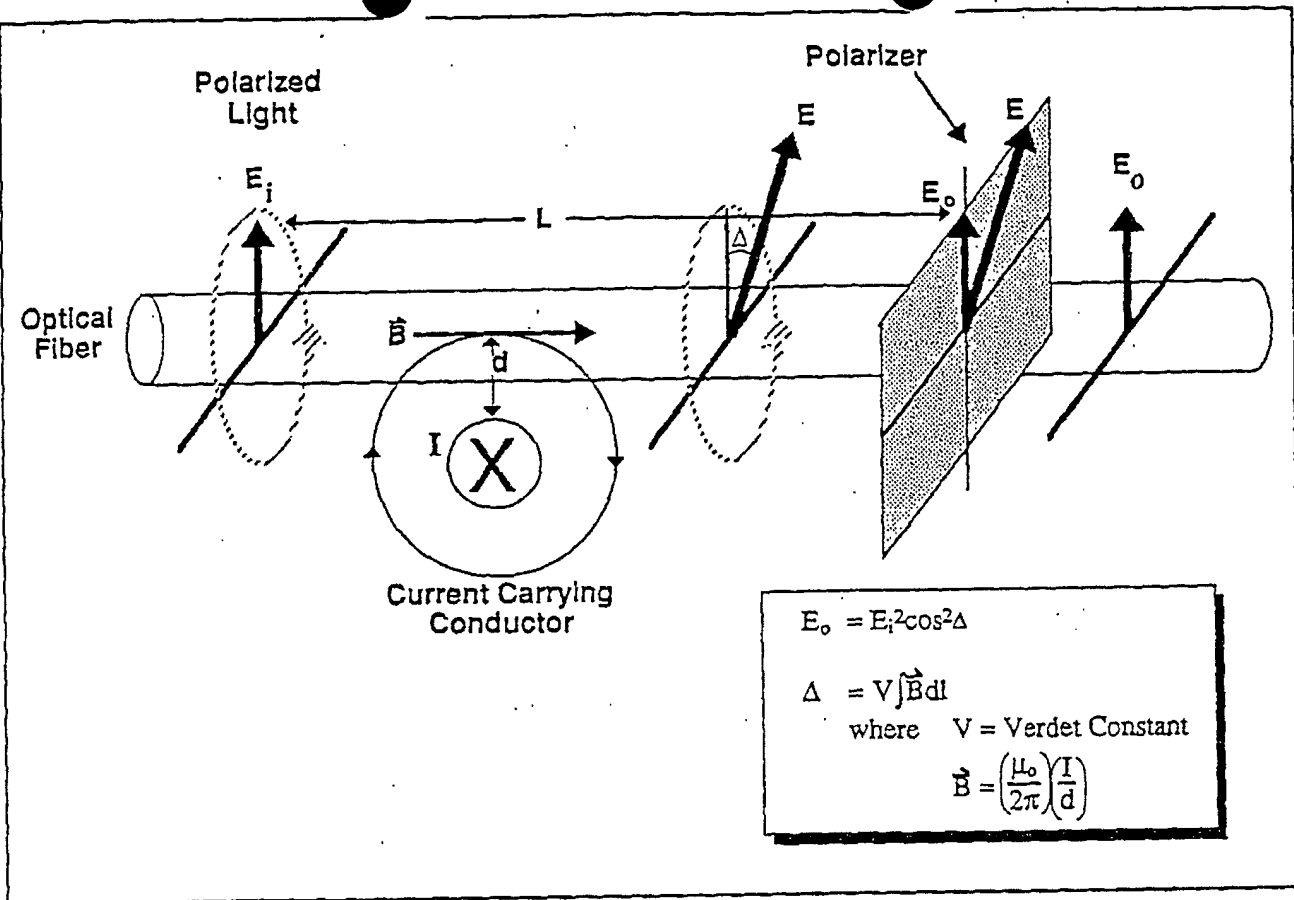


Figure 12 Optical Current Measurement

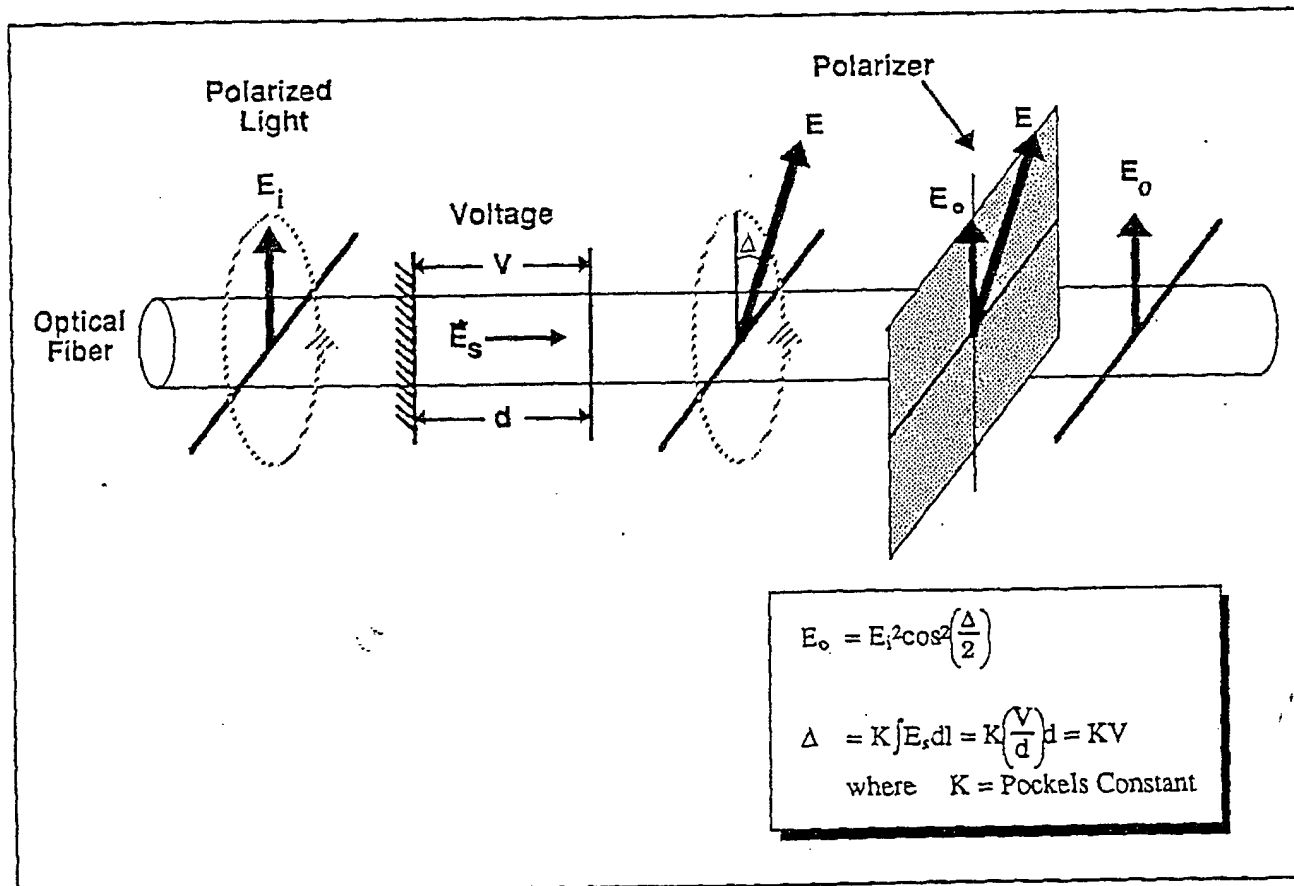


Figure 13 Optical Voltage Measurement

	MSA	HALL	TRANS	A/D
	0.2 - 0.5	0.5 - 1.0	0.5 - 1.0	0.1 - 0.5
Accuracy (%)	A	C+	C+	C
Low end performance	A	B	B	B
High end performance	A	B	B	B-
Linearity (low-high)	B+	B-	B-	A
Temperature performance	B	B-	B-	B
Long-term stability	A-	A	A	B
Reliability	A-	A-	A-	A
Isolation/SWC	B	A	A	C
Single phase cost	C	C	B	A
Polyphase (xfmr rated) cost	C			A
Polyphase (self-contained) cost	C	C	C	A
VA/VAR/P.F. capability	C	C	C	A
Flexibility	C	C	C	A
Installation diagnostics	B	B	B	B
Reduced test time	B	C	C	A
Ease of calibration				

A = excellent B = good C = fair

Figure 14 Metering Technology Rating

For the industrial polyphase market, there is a clear winner in the presented technologies - digital sampling. This technology provides excellent accuracy, above average stability and reliability, and the highest degree of versatility and functionality. Essential to the ascendancy of digital sampling is its inherent ability to measure voltage, current, and all three of active, reactive, apparent powers, on a per-phase basis.

The remainder of this paper details the features and applications of electronic metering focusing on digital sampling technology in the industrial market place.

3. FEATURES AND APPLICATIONS

The solid state digital sampling meter of today offers a wide variety of features for billing and non-billing applications. From the choice of power calculation methods, to power quality measurement, interval data recording, Time-Of-Use, load control, and remote metering reading capabilities. Of course, some these features are not limited to digital sampling meters only. However, since digital sampling meters require a fairly high powered microprocessor, the level of integration enabling these features is accomplished more readily.

3.1 POWER CALCULATION METHODS

Everyone in the metering industry will agree unanimously on the method of calculating real, or active, power. However, the calculation of apparent power does not share the same degree of industry approval. Of late, a great deal of controversy has surfaced in the calculation of apparent power, particularly in three phase, three wire installations under unbalanced conditions.

The two basic methods of calculating apparent power are vectorial and arithmetic. The vectorial method correctly meters all installations (form factors) under balanced or unbalanced conditions. The arithmetic method, on the other hand, fails to correctly meter the three phase, three wire, installation under unbalanced conditions. However, arithmetic apparent power is correct in the presence of harmonic distortion while vectorial apparent power is not. Fueling the controversy is the admonition that the three phase, three wire, installation is itself incorrect since it fails to provide a way to accurately determine the third current under unbalanced loads.

A digital sampling meter has the ability to calculate apparent power either vectorially or arithmetically. It can also employ a combination of the two. It is

possible to derive the B phase current vectorially from the A and C phase currents, and then calculate apparent power arithmetically. This combined method limits the absolute error to less than 15% under a 100% unbalanced load (single phase load), while including harmonic content. It should be noted, however, that this hybrid apparent power calculation method is not approved for billing in Canada.

3.2 PER-PHASE QUANTITIES

Another beneficial characteristic of digital sampling technology is its inherent ability to provide both per-phase and aggregate values for all measured quantities. Aggregate quantities are used principally for billing, whereas per-phase quantities are used primarily for installation and meter verification.

Connection verification can be demonstrated quickly and easily from per-phase voltage and current values. The lack of, or incorrect magnitude of, any voltage or current may point to an incorrect or faulty connection. Once correct connection to a service has been established, per-phase quantities can be utilized for load balance analysis. Although most solid-state meters do not perform this function per se, a simple voltage unbalance can be calculated by comparing per-phase values against the average of all phases.

Given the volume of available data that such a meter has to offer, it is advantageous to incorporate multiple means by which this information may be extracted. To address this issue, most electronic meters manufactured today include an industry standard optical communications port for data transfer.

3.3 PC INTERFACING FOR SPECIAL APPLICATIONS

The inclusion of data communications facilities enables an electronic meter to interchange data with the outside world. Special purpose applications that interact with the meter on an occasional basis are, for economic reasons, better left external to the meter. Common applications include those capable of creating and programming meteorological parameters and configurations, load profile interrogation and manipulation, as well as a new generation of installation diagnostic tools.

Utilizing the meter's ability to provide per-phase quantities, rather complex applications have been created to verify and diagnose installations. Capabilities include the ability to graphically display real-time three-phase vector diagrams of the installation, perform load profiling and load balance analy-

sis, and even give rudimentary information with regard to the presence of harmonic distortion.

Automatic meter reading via remote communications is another area that is seeing growth in the metering industry. By coupling the basic communications facilities to various existing communication media, meter data becomes accessible from a remote location, allowing utilities to perform billing more or less autonomously. Added benefits of these automatic systems include tamper monitoring and, to a certain extent, fault detection. Remote meter reading is addressed separately in Section 3.8.

3.4 POWER QUALITY

The issues surrounding quality power are beginning to garner a great deal of industry fervor. Surges or sags, often less than a millisecond in duration, are not uncommon to the power line and rarely caused problems with older equipment. Today, however, the massive infiltration of microelectronics into common industrial and household equipment has brought these power disturbances to the attention of the general public.

Particularly susceptible are microprocessor controlled digital systems which, due to their high operating speed and low operating power, are intolerant of even the most minute variations in their operating environment. The most common sources of problems are power supply irregularities caused by variations in the supply voltage. High frequency noise, or transients, conducted by the power line can also wreak havoc with digital devices. These disturbances are coupled to the electronic circuitry directly, through stray capacitance in power transformers, or capacitively through radiated energy which is impressed upon circuit paths that behave as antennae for these high frequency signals.

Numerous sources contribute to the overall cause of power line disturbances. Most influential, however, are nonlinear loads, which are the foundation of harmonic distortion. Harmonic distortion is the number one cause of power line disturbances leading to equipment failure. Problems related to the presence of high levels of harmonic currents in power systems not designed for nonlinear loads are abundant; overloading of unprotected neutral conductors by triplen harmonics; nuisance tripping of circuit breakers; low power factor yielding poor utilization of available power; overheating of distribution transformers; and burned-out computer equipment, or scrambled and lost data.

It has been recently estimated that power related problems cost North American companies approxi-

mately \$26 billion a year in lost time and revenue. To address these issues, many utilities have begun power quality programs. Similarly, standards associations like the CSA have also begun researching power quality. A working group has been formed within the CSA with the mandate to quantify the measurement of harmonic distortion and impose limits on the sources of harmonic producing equipment. The fundamental problem facing most utilities is the lack of cost effective measurement equipment with which they can assess the degree of the problem, and standards within which they can bound the problem.

First generation tools to gauge harmonic distortion can be constructed by employing the measurement versatility of digital sampling meters meeting two criteria.

First, the sampling technique utilized must be capable of measuring voltage and current at frequencies higher than the fundamental. This can be accomplished by sampling at the Nyquist frequency, or at a rate that is at least twice as fast as the highest order harmonic that is to be quantified, or by migrating the sampling through all points of a complete cycle over time. The latter technique requires the harmonic distortion to be in a steady-state condition for the duration of the migration (usually one second).

Second, the meter must be capable of calculating both arithmetic and vectorial volt-amperes. By comparing these two quantities, an approximation of the harmonic distortion seen by the load can be derived. This is accomplished by means of a theory which states that vectorial volt-amperes under non-sinusoidal conditions are equal to the square root of the sum of the squares of active power, reactive power, and distortion power and that this is equal to arithmetic volt-amperes (see Figure #15). Note that this relationship holds true if the active and reactive power terms are comprised of the fundamental components of voltage and current only, and that it is direction insensitive. That is to say that this relation cannot be used to determine the source of the distortion, only the magnitude.

With the advent of faster microprocessors, second generation tools should be available within the next few years. These meters will be capable of sampling at higher rates and performing complex mathematical functions, such as Fast Fourier Transforms, with the data they gather. Conceivably, devices such as these could bring about billing structures with harmonic distortion clauses similar to today's existing power factor penalty clauses.

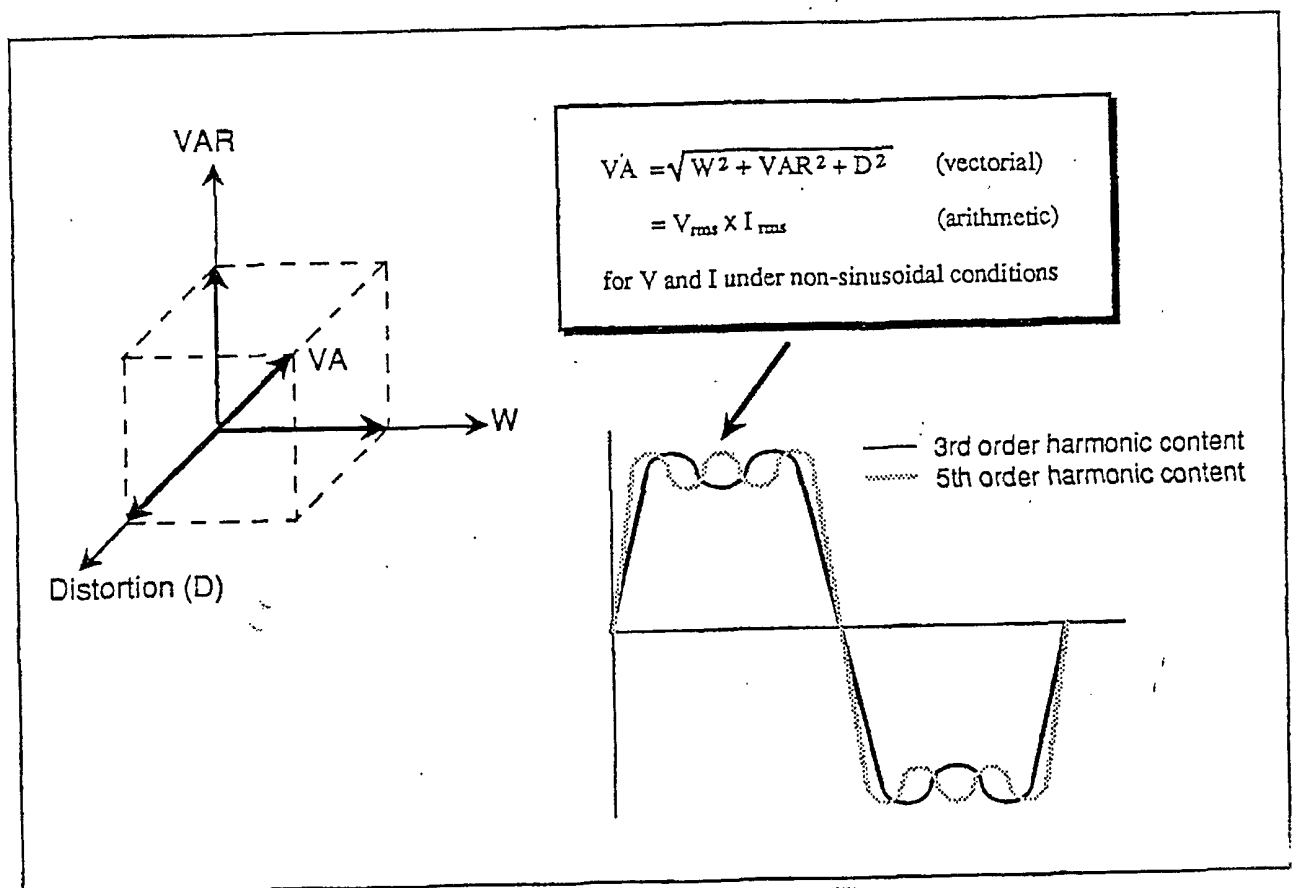


Figure 1 Electromechanical Meter History

3.5 TIME-OF-USE

Potentially the most exploited application in solid-state metering, and conceivably one of the progenitors of electronic attachments, is Time-Of-Use. This method of billing has been utilized for some time in the U.S. within both industrial and residential markets and is now seeing an emergence in Canada. Basically, Time-Of-Use enables a meter to accumulate energy and demand into separate bins, or rates, during different time intervals of the day. These individual bins can then be billed separately according to the cost of providing the energy at the given time interval of the day.

Time-Of-Use enables a utility to excise compensation proportional to the total cost of producing energy. For example, in the residential market there is an increased demand for energy around the dinner hour for which the utility may have to increase production incrementally. If the increased supply were not completely consumed, the utility could be faced with a net loss. However, if the utility can increase the cost of energy specifically during this time of the day, they can bill in proportion to the cost incurred by the increase in the total available capacity.

To be effective, Time-Of-Use metering requires fairly static load profiles over time. Most implementations employ multi-rate capabilities with time intervals programmable, within seasons, over numerous years. To be successful, especially in the residential arena, Time-Of-Use requires significant social acceptance and customer education. Time-Of-Use does not specifically benefit from any underlying metering technology — it is equally applicable to all forms.

3.6 LOAD CONTROL

With the advent of microprocessor technology, the sophistication of load control capabilities has increased substantially. Previously, a standard meter's facilities were limited to KYZ relay closures. Now outputs can have independently programmable on-off switch points coincident with Time-Of-Use schedules, or demand thresholds, or even override control from a remote source for real-time pricing applications.

Basically, once the circuitry for an output exists it can be opened and closed on any asynchronous or synchronous event occurring in the meter. All control is accomplished via software management of the hardware. Load control, especially real-time, still remains an open area that will be subject to much further growth as Demand Side Management and related activities become reality.

3.7 UNDER-THE-GLASS RECORDERS

Load recording, or profiling, is a well known procedure in the metering industry. As mentioned previously, advanced functions such as Time-Of-Use depend heavily on well established load profiles. In past generations of metering equipment, load recorders were separate devices fed by KYZ pulses emitted from meters.

With solid-state metering, "under the glass" recorders become feasible with the addition of nonvolatile memory and a real-time clock. Digital sampling meters are particularly suitable to profiling due to the plethora of measured and derived values they have to offer. Most common combinations will find both load profiling and Time-Of-Use functions within the same electronic meter since the latter owes its existence to the former.

3.8 REMOTE METER READING

Remote meter reading is a direct spinoff of the communications industry. For every type of media for which there exists a means to communicate, there is a remote meter reading application. It can safely be said that there are more ways to read a meter remotely than there are ways for the meter to measure and accumulate the quantities of interest.

Whether the media is telephone, cellular telephone, cable T.V., radio, power line, optical fiber, or even satellite, there are only two basic modes of operation. Either the meter initiates the communications transaction, or something else does. Using simple telephone as an example, these two methodologies are termed dial inbound and dial outbound. A dial inbound meter is programmed to "call home" at a predetermined time or in the event of an emergency such as detected tampering. A dial outbound meter never initiates a call, it simply responds to incoming calls.

Underlying the basic simplicity of these methodologies is the necessity for a fairly robust communications protocol. This protocol must handle all aspects of a data transfer, including: identification and authentication of the communicating devices; the parceling and distribution of requested data; and the detection and possible correction of any errors within said data. To be particularly effective, the protocol must handle any media dependent requirements, presenting the same external interface to each. Although many protocols exist within both the computer communications industry and the metering industry, there does not exist one universal protocol that is applicable to both. To address this problem, recent standardization efforts have begun in Canada by the Consumer and Corporate Affairs Canada (CCAC) chaired Protocol Task Force.

Remote meter reading brings the realm of systems to metering. Fairly large central computers or distributed and networked smaller computers must be put in place to manage the reading and reporting of meter bills. In addition to performing basic reading and billing functions, such systems can be used as information sources for other utility functions. For example, meters with battery backup capabilities could alert the central billing system in the event of a power failure. The central system in turn maps out the physical boundaries of the power failure from the known locations of all calling meters. This information can be used to dispatch repair crews, or give customer service representatives added knowledge regarding the scope of the failure. A central, on-line billing system can also augment the billing function by providing totalization of distributed locations via summary billing.

3.9 METER SHOP REQUIREMENTS

The versatility and flexibility of solid-state metering does come with a price — increased complexity, which can become a source of concern in the utility meter shop, where the correct functionality of the meter is to be tested.

Most manufactures alleviate most of the complexity by offering personal computer based software packages that program, calibrate, and test their meters. A great deal of intelligence can be built in to these packages, enabling the meter shop to mitigate much of the learning curve imposed by this new technology. This of course requires that the meter shop employee possess a sound knowledge of personal computers, including their basic principle of operation, and familiarity with several software packages.

Additionally, most meter shops will require upgrades to existing test equipment. The higher resolution and accuracy of solid-state meters requires more accurate multifunction standards, test benches with greater load regulation capabilities, synthesized signal generators for the creation of arbitrary waveforms to test harmonic distortion response, and communications equipment with which to carry out all the testing. With most of these items, as with the personal computers, some degree of education will be required.

Unfortunately, some features are beyond the capabilities of the meter shop to test — the testing of an automatic meter reading system that is to handle several hundred thousand meters, or the testing of a twenty year Time-Of-Use schedule, for example. Some features will have to be verified primitively with their performance extrapolated to encompass the entire test.

4. FUTURE DIRECTIONS

The transformation of metering into the domain of solid-state technology is here to stay. The added versatility, functionality, and accuracy of these devices ensures their acceptance and longevity in the metering market place. However, to be truly cost competitive with the ubiquitous induction meter, this technology must still grow and mature.

One direction that promises reasonable cost containment without sacrificing any versatility is in distributing the data acquisition and control functions. This methodology decomposes the functionality of a solid state meter into its elemental, or atomic, parts and distributes these along a network. Cost containment is realized by utilizing simpler, and thus cheaper, technology in the atomic units. Functionality and ultimate versatility is realized by allowing any number of these elemental devices to be networked together.

A basic network would be comprised of a fundamental measurement device, and a display device. Additional devices could be added for Time-Of-Use metering, load profiling, harmonic distortion monitoring, load control, and remote meter reading, each snapping into the network like a "Lego" building block. The network would have to be simple and cost effective, and allow device interconnection by means of existing media such as the power line itself.

Today this system would not be possible because the network cost alone would be greater than that of a fully functional solid-state meter. However, certain enabling technologies have appeared on the horizon holding much promise that this will be possible soon.

5. CONCLUSIONS

The metering industry is in the throes of a metamorphosis described by many as the computer or semiconductor revolution. Computer industry pundits say that the real revolution has yet to begin, that what we have encountered to date is merely sabre rattling. Whether or not this is true is really irrelevant. Suffice it to say that the metering industry has plunged into the electronic age and is not looking back.

The capability of products is undergoing radical change. The number of available products is increasing, with the average lifespan of these products decreasing due to premature obsolescence. The industry must meet these changes in a pro-active manner, with utilities and manufacturers jointly developing viable and cost effective solutions.